

1 IRRIGATED CATHETER HAVING A POROUS TIP ELECTRODE

5 FIELD OF THE INVENTION

The present invention is directed to an irrigated catheter having a porous tip electrode.

10 BACKGROUND OF THE INVENTION

Electrode catheters have been in common use in medical practice for many years. They are used to map electrical activity in the heart and to ablate sites of aberrant electrical activity.

15 In use, the electrode catheter is inserted into a major vein or artery, e.g., the femoral artery, and then guided into the chamber of the heart which is of concern. Within the heart, the ability to control the exact position and orientation of the catheter tip is critical and largely determines the usefulness of the catheter.

20 In certain applications, it is desirable to have the ability to inject and/or withdraw fluid through the catheter. One such application is a cardiac ablation procedure for creating lesions which interrupt errant electrical pathways in the heart. Traditionally, this has been accomplished with an irrigated tip catheter.

25 A typical ablation procedure involves the insertion of a catheter having a tip electrode at its distal end into a heart chamber. A reference electrode is provided, generally taped to the patient's skin. Radio frequency (RF) current is applied to the tip electrode, and flows through the surrounding media, i.e., blood and tissue, toward the reference electrode. The distribution of current depends on the amount of electrode surface in contact with the tissue, as compared to blood which has a higher conductivity than the tissue. Heating of the tissue occurs due to its electrical resistivity. The tissue is heated sufficiently to cause 30 cellular destruction in the cardiac tissue resulting in

1 formation of a lesion within the cardiac tissue which is
electrically non-conductive. During this process, heating of
the electrode also occurs as a result of conduction from the
heated tissue to the electrode itself. If the electrode
5 temperature becomes sufficiently high, possibly above 60°C, a
thin transparent coating of dehydrated blood can form on the
surface of the electrode. If the temperature continues to
rise, this dehydrated layer of blood can become progressively
thicker resulting in blood coagulation on the electrode
10 surface. Because dehydrated biological material has a higher
electrical resistance than endocardial tissue, impedance to
the flow of electrical energy into the tissue also increases.
If the impedance increases sufficiently, an impedance rise
15 occurs and the catheter must be removed from the body and the
tip electrode cleaned.

In a typical application of RF current to the
endocardium, circulating blood provides some cooling of the
ablation electrode. However, there is typically a stagnant
area between the electrode and tissue which is susceptible to
20 the formation of dehydrated proteins and coagulum. As power
and/or ablation time increases, the likelihood of an impedance
rise also increases. As a result of this process, there has
been a natural upper bound on the amount of energy which can
25 be delivered to cardiac tissue and therefore the size of RF
lesions. Historically, RF lesions have been hemispherical in
shape with maximum lesion dimensions of approximately 6 mm in
diameter and 3 to 5 mm in depth.

In clinical practice, it is desirable to reduce or
eliminate impedance rises and, for certain cardiac arrhythmias,
30 to create larger lesions. One method for accomplishing this
is to monitor the temperature of the ablation electrode and to
control the RF current delivered to the ablation electrode
based on this temperature. If the temperature rises above a
35 pre-selected value, the current is reduced until the
temperature drops below this value. This method has reduced

1 the number of impedance rises during cardiac ablations but has
not significantly increased lesion dimensions. The results
are not significantly different because this method continues
5 to rely on the cooling effect of the blood which is dependent
on the location within the heart and the orientation of the
catheter to the endocardial surface.

10 Another method is to irrigate the ablation electrode, e.g., with physiologic saline at room temperature, to actively cool the ablation electrode instead of relying on the more
passive physiological cooling provided by the blood. Because
15 the strength of the RF current is no longer limited by the
interface temperature, current can be increased. This results
in lesions which tend to be larger and more spherical, usually
measuring about 10 to 12 mm.

15 The clinical effectiveness of irrigating the ablation electrode is dependent upon the distribution of flow within
the electrode structure and the rate of irrigation flow
through the tip. Effectiveness is achieved by reducing the
overall electrode temperature and eliminating hot spots in the
20 ablation electrode which can initiate coagulum formation.
More channels and higher flows are more effective in reducing
overall temperature and temperature variations, i.e., hot
spots. The coolant flow rate must be balanced against the
25 amount of fluid that can be injected into the patient and the
increased clinical load required to monitor and possibly
refill the injection devices during a procedure. In addition
to irrigation flow during ablation, a maintenance flow,
typically a lower flow rate, is required throughout the
30 procedure to prevent backflow of blood into the coolant
passages. Thus, reducing coolant flow by utilizing it as
efficiently as possible is a desirable design objective.

35 One method for designing an ablation electrode which
efficiently utilizes coolant flow is the use of a porous
material structure. One such design is described in U.S.
Patent No. 6,405,078 to Moaddeb et al., the entire disclosure

1 of which is incorporated herein by reference. Moaddeb
describes the use of sintered metal particles to create a
porous tip electrode. In addition, Moaddeb uses a non-
5 conductive insert implanted into the porous tip electrode for
mounting a thermocouple, lead wire and/or irrigation tube
within the porous tip electrode. However, during irrigation
the sintered metal particles can disintegrate and break away
from the electrode structure. Consequently, a desire arises
for a porous electrode having increased structural integrity.

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SUMMARY OF THE INVENTION

In one embodiment, the invention is directed to an irrigated catheter having a porous tip electrode. The catheter comprises a catheter body and a tip section. The catheter body has an outer wall, proximal and distal ends, and a lumen extending therethrough. The tip section comprises a segment of flexible tubing having proximal and distal ends and at least one lumen therethrough. The proximal end of the tip section is fixedly attached to the distal end of the catheter body. The porous tip electrode is fixedly attached to the distal end of the tubing of the tip section. The tip electrode comprises a porous material through which fluid can pass.

The porous tip electrode comprises sintered non-conductive material. The sintered material may be made from any suitable non-conductive polymer or ceramic material. The sintered particles comprise both small particles and large particles, the large particles having a mean diameter at least about 2.5 times greater, and preferably, about 4 times greater, than the mean diameter of the small particles. The use of differently sized particles helps control the porosity of the sintered material, promotes uniform flow of fluid through the porous material, and minimizes fluid pressure drop through the material. The porous tip electrode is covered with a thin metal coating that is webbed, or otherwise porous,

1 with openings through which fluid can pass to the outer
surface of the tip electrode. The sintered polymeric or
ceramic material has improved resistance to disintegration
during irrigation. The metal coating improves overall
5 structural stability of the tip electrode and serves as an
electrode for conducting radio-frequency energy to the target
tissue.

10 The catheter further comprises an irrigation tube having
proximal and distal ends. The irrigation tube extends through
the central lumen in the catheter body, with the distal end of
the irrigation tube in fluid communication with the proximal
end of the passage in the tip electrode. By this design, the
fluid can flow through the irrigation tube, into the passage
15 in the tip electrode and through the porous material and
porous coating of the tip electrode to the outer surface of
the tip electrode. A temperature sensing means is mounted in
a blind hole in the tip electrode. A puller wire is mounted
in the tip section. An electrode lead wire is electrically
connected to the proximal end of the tip electrode.

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BRIEF DESCRIPTION OF THE DRAWINGS

25 These and other features and advantages of the present
invention will be better understood by reference to the
following detailed description when considered in conjunction
with the accompanying drawings wherein:

FIG. 1 is a side view of an embodiment of the catheter of
the invention;

30 **FIG. 2** is a side cross-sectional view of a catheter body
according to the invention, including the junction between the
catheter body and tip section.;

FIG. 3A is a side cross-sectional view of a catheter tip
section showing the lumens for the fluid passage and puller
wire;

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1 **FIG. 3B** is a side cross-sectional view of the catheter tip section of **FIG. 3A** showing the lumens for the fluid passage, thermocouple and electrode lead wires;

5 **FIG. 4** is a longitudinal cross-sectional view of the tip section illustrated in **FIGs. 3A** and **3B**;

10 **FIG. 5** is a side cross-sectional view of an alternative embodiment of a catheter body according to the invention having a side arm for an irrigation tube;

15 **FIG. 6** is a side view of a tip electrode according to the invention depicting one method of attaching the electrode lead wire to the tip electrode;

15 **FIG. 7** is a side cross-sectional view of a tip electrode according to the invention depicting the arrangement of the irrigation tube and temperature sensing means within the tip electrode;

20 **FIG. 8** is a close-up cross-sectional view of the distal section of the tip electrode taken along line 8-8 in **FIG. 7**;

20 **FIG. 9** is a side cross-sectional view of an alternative tip section according to the invention that houses an electromagnetic sensor; and

25 **FIG. 10** is a close-up view of a portion of the surface of the tip electrode depicting one embodiment of the porous coating disposed over the porous surface of the tip electrode.

25 DETAILED DESCRIPTION OF THE INVENTION

30 In a particularly preferred embodiment of the invention, there is provided a steerable catheter having an irrigated tip. As shown in **FIGs. 1** to **4**, catheter **10** comprises an elongated catheter body **12** having proximal and distal ends, a tip section **14** at the distal end of the catheter body **12**, and a control handle **16** at the proximal end of the catheter body **12**.

35 With reference to **FIG. 2**, the catheter body **12** comprises an elongated tubular construction having a single, axial or central lumen **18**. The catheter body **12** is flexible, i.e.,

1 bendable but substantially non-compressible along its length. The catheter body 12 can be of any suitable construction and
5 made of any suitable material. A presently preferred construction comprises an outer wall 22 made of a polyurethane or PEBAK. The outer wall 22 comprises an imbedded braided mesh of high-strength steel, stainless steel or the like to increase torsional stiffness of the catheter body 12 so that, when the control handle 16 is rotated, the tip section 14 of
10 the catheter 10 will rotate in a corresponding manner. The outer diameter of the catheter body 12 is not critical, but is preferably no more than about 8 french, more preferably about 7 french, still more preferably about 5 french. Likewise, the thickness of the outer wall 22 is not critical, but is thin enough so that the central lumen 18 can accommodate an
15 irrigation tube, a puller wire, lead wires, and any other wires, cables or tubes. The inner surface of the outer wall 22 is lined with a stiffening tube 20, which can be made of any suitable material, such as polyimide or nylon. The stiffening tube 20, along with the braided outer wall 22,
20 provides improved torsional stability while at the same time minimizing the wall thickness of the catheter, thus maximizing the diameter of the central lumen 18. The outer diameter of the stiffening tube 20 is about the same as or slightly smaller than the inner diameter of the outer wall 22.
25 Polyimide tubing is presently preferred for the stiffening tube 20 because it may be very thin walled while still providing very good stiffness. This maximizes the diameter of the central lumen 18 without sacrificing strength and stiffness. A particularly preferred catheter has an outer wall 22 with an outer diameter of from about 0.090 inches to about 0.098 inches and an inner diameter of from about 0.061 inches to about 0.065 inches and a polyimide stiffening tube 20 having an outer diameter of from about 0.060 inches to about 0.064 inches and an inner diameter of from about 0.051 inches to about 0.056 inches.

1 As shown in **FIGS. 3A, 3B, and 4**, the tip section **14** comprises a short section of tubing **19** having three lumens **30, 32** and **34**. The tubing **19** is made of a suitable non-toxic material that is preferably more flexible than the catheter body **12**. A presently preferred material for the tubing **19** is braided polyurethane, i.e., polyurethane with an imbedded mesh of braided high-strength steel, stainless steel or the like. The outer diameter of the tip section **14**, like that of the catheter body **12**, is preferably no greater than about 8 french, more preferably about 7 french, still more preferably about 5 french. The size of the lumens is not critical. In a particularly preferred embodiment, the tip section **14** has an outer diameter of about 7 french (0.092 inches) and the first lumen **30** and second lumen **32** are generally about the same size, each having a diameter of from about 0.020 inches to about 0.024 inches, preferably about 0.022 inches, with the third lumen **34** having a slightly larger diameter of from about 0.032 inches to about 0.038 inches, preferably about 0.036 inches.

20 A preferred means for attaching the catheter body **12** to the tip section **14** is illustrated in **FIG. 2**. The proximal end of the tip section **14** comprises an outer circumferential notch **24** that receives the inner surface of the outer wall **22** of the catheter body **12**. The tip section **14** and catheter body **12** are attached by adhesive (e.g. polyurethane glue) or the like. Before the tip section **14** and catheter body **12** are attached, however, the stiffening tube **20** is inserted into the catheter body **12**. The distal end of the stiffening tube **20** is fixedly attached near the distal end of the catheter body **12** by forming a glue joint (not shown) with polyurethane glue or the like. Preferably, a small distance, e.g., about 3 mm, is provided between the distal end of the catheter body **12** and the distal end of the stiffening tube **20** to permit room for the catheter body **12** to receive the notch **24** of the tip section **14**. A force is applied to the proximal end of the

1 stiffening tube 20, and, while the stiffening tube 20 is under compression, a first glue joint (not shown) is made between the stiffening tube 20 and the outer wall 22 by a fast drying glue, e.g. Super Glue®. Thereafter, a second glue joint (not shown) is formed between the proximal ends of the stiffening tube 20 and outer wall 22 using a slower drying but stronger glue, e.g. polyurethane.

At the distal end of the tip section 14 is a tip electrode 36. Preferably, the tip electrode 36 has a diameter about the same as the outer diameter of the tubing 19. The tip electrode 36 is formed of any suitable non-conductive polymer, such as polyethylene or Teflon®, or ceramic material, in which holes are drilled. The porous non-conductive material can be made using any conventional technique. For example, the porous non-conductive material can be machined from a rod of the material. Preferably, however, the non-conductive polymer comprises sintered polymer particles 86 formed from polyethylene or Teflon®, as best depicted in FIG. 8. As used herein, the term "sinter" refers to the process of bonding adjacent particles in a powder mass or compacting the particles by heating them to a temperature below the melting point of the main constituent at a predetermined and closely controlled time-temperature regime, including heating and cooling phases, in a protective atmosphere. The sintered polymer particles 86 permit passage of a cooling fluid through the tip electrode, as described in more detail below. The porosity of the sintered material is controlled by the amount of particle compacting in the mold or glue, the particle size, and the particle distribution.

A particularly preferred sintering process involves providing polyethylene or Teflon® powder particles in a certain sieve fraction, e.g., in the range of from about 5 microns to about 250 microns. The particles are preferably in the range of from about 10 microns to about 100 microns. In a particularly preferred embodiment, at least two different

1 sized particles can be provided. For example, particles in
the range of from about 15 microns to about 30 microns, and
more preferably about 20 microns, in combination with
5 particles in the range of from about 80 microns to about 110
microns, and more preferably about 100 microns, could be used.
When two different sized particles are used, preferably the
larger particles have a mean diameter at least about 2.5 times
greater than the mean diameter of the smaller particles, and
more preferably at least about 4 times greater.
10 Alternatively, a single particle size can be used, which can
give a denser packing and result in a higher pressure drop
across the porous electrode. Whatever polymer is used, the
particles are preferably rounded, and more preferably
spherical, so as to provide a tip electrode surface that is
15 not rough. However, the particles can be irregularly shaped,
i.e. having differing shapes, which is a low cost alternative.

In a preferred process, the particles are put into a
mold, such as a ceramic mold, having the desired electrode
shape. If desired, the particles can be mixed with a
20 suitable binder prior to being put into the mold. When a
binder is used, the mold containing the binder and particles
is placed into a low temperature oven and heated to a
temperature sufficient to evaporate the binder. The particles
25 are then sintered under vacuum or air at a temperature ranging
from about 80°C to about 160°C, although the temperature can
vary depending on the composition of the porous polymer.
However, the temperature should be below the melting point of
the composition. The resulting tip electrode is then removed
30 from the mold and assembled onto the flexible tubing of the
tip section.

A tip electrode prepared in accordance with this method
is depicted in **FIG. 8**. In particular, **FIG. 8** illustrates the
porosity of the tip electrode when particles of different
35 sizes are used. Although the drawings of the tip electrode,
such as **FIGs. 3A** and **3B**, do not depict the porous sintered

1 material in detail, it is to be understood that where the body
of the tip electrode is described as being made of a porous
sintered material, it appears generally as depicted in **FIG. 8**.
The drawings, such as **FIGs. 3A** and **3B**, are provided to more
5 clearly show the additional components in the tip section.

As shown in **FIGs. 3A** and **3B**, the tip electrode **36** has two
cavities extending therein, namely a primary fluid passage **35**
and a blind hole **31** that correspond in size and location to
the lumens **34** and **30**, respectively, in the tip section **14**.
10 The primary fluid passage **35** extends substantially all the way
through the sintered material of the tip electrode **36**,
preferably ending just before the distal end of the tip
electrode **36**. The blind hole **31** extends only a part of the
way through the sintered material of the tip electrode **36**,
15 preferably about half the length of the tip electrode **36** or
less. For example, for a 3.5 mm tip electrode **36**, the blind
hole **31** is about 0.088 inches long.

Disposed over the surface of the porous tip electrode is
a thin metal coating **84**, as depicted in **FIG. 10**. The metal
coating **84** serves to impart improved structural integrity to
the porous tip electrode **36** while also serving as an electrode
for distributing radio-frequency energy to the target tissue.
The metal coating **84** can be made of any conductive metal, e.g.
platinum or gold. Preferably, the metal coating **84** is made of
25 a platinum-iridium alloy; e.g. 90% Platinum/10% Iridium,
applied to the surface of the porous tip electrode **36** by a
deposition process impregnating a thin layer of platinum-
iridium alloy onto the porous surface of the tip electrode **36**.
The thickness of the metal coating **84** may vary as desired, but
30 is sufficiently thin to maintain a porous electrode surface,
and sufficiently thick to maintain a conductive surface. For
example, the metal coating **84** may have a thickness ranging
from 0.2 μ m to about 2 μ m. Preferably, as shown in **FIG. 10**,
the metal coating **84** is webbed or otherwise porous with

1 openings **85** in the metal coating **84** through which irrigation fluids can pass.

5 A preferred tip electrode has a length ranging from about 2.5 mm to about 8 mm, preferably about 3.5 mm. Preferably, the tip electrode **36** is attached to the tubing **19** by polyurethane glue or the like. The wires and tubes that extend into the tip electrode **36**, described in more detail below, help to keep the tip electrode in place on the tubing **19** of the tip section **14**.

10 In the embodiment shown in **FIGS. 3A** and **3B**, there are three ring electrodes **39** mounted on the tubing **19** proximal to the tip electrode **36**. It is understood that the presence and number of ring electrodes **39** may vary as desired. Each ring electrode **39** is slid over the tubing **19** and fixed in place by glue or the like. The ring electrodes **39** can be made of any suitable material, and are preferably machined from platinum-iridium bar (90% platinum/10% iridium).

15 The tip electrode **36** and ring electrodes **39** are each connected to a separate lead wire **44**. The lead wires **44** extend through the first lumen **30** of tip section **14**, the central lumen **18** of the catheter body **12**, and the control handle **16**, and terminate at their proximal ends in an input jack (not shown) that may be plugged into an appropriate monitor (not shown). The portion of the lead wires **44** extending through the central lumen **18** of the catheter body **12**, control handle **16** and proximal end of the tip section **14** may be enclosed within a protective sheath **49**, which can be made of any suitable material, preferably polyimide. The protective sheath **49** is preferably anchored at its distal end to the proximal end of the tip section **14** by gluing it in the first lumen **30** with polyurethane glue or the like. The lead wires **44** are attached to the tip electrode **36** and ring electrodes **39** by any conventional technique. For example, as described below, the tip electrode **36**, in one embodiment, may have a distal section **70** having a greater diameter than the

1 diameter of proximal section 68. In this embodiment, as
depicted in **FIG. 6**, connection of a lead wire 44 to the tip
electrode is accomplished, for example, by coiling the lead
wire 44 around the proximal portion of the tip electrode 36
5 and gluing it in place to the metal coating 84 with
polyurethane glue or the like.

10 Connection of a lead wire 44 to a ring electrode 39 is
preferably accomplished by first making a small hole through
the tubing 19. Such a hole can be created, for example, by
inserting a needle through the tubing 19 and heating the
needle sufficiently to form a permanent hole. A lead wire 44
15 is then drawn through the hole by using a microhook or the
like. The ends of the lead wire 44 are then stripped of any
coating and soldered or welded to the underside of the ring
electrode 39, which is then slid into position over the hole
and fixed in place with polyurethane glue or the like.

20 An irrigation tube is provided within the catheter body
12 for infusing fluids, e.g. saline, to cool the tip electrode
36. The irrigation tube may be made of any suitable material,
and is preferably made of polyimide tubing. A preferred
irrigation tube has an outer diameter of from about 0.032
inches to about 0.036 inches and an inner diameter of from
about 0.027 inches to about 0.032 inches.

25 With reference to **FIGs. 2** and **3A**, the irrigation tube
comprises multiple tube segments. A first irrigation tube
segment 46 extends through the central lumen 18 of the
catheter body 12 and terminates in the proximal end of the
third lumen 34 of the tip section 14. The distal end of the
first irrigation tube segment 46 is anchored in the third
30 lumen 34 by polyurethane glue or the like. The proximal end
of the first irrigation tube segment 46 extends through the
control handle 16 and terminates in a luer hub 47 or the like
at a location proximal to the control handle. A second
irrigation tube segment 48 is provided at the distal end of
35 the third lumen 34 and extends into the primary fluid passage

1 35 of the tip electrode 36. The second irrigation tube
segment 48 is anchored by polyurethane glue or the like within
the third lumen 34 of the tip section 14 and in the primary
fluid passage 35. The second irrigation tube segment 48
5 provides additional support to maintain the tip electrode 36
mounted on the tubing 19. In practice, fluid is injected into
the first irrigation tube segment 46, through the third lumen
34, through the second irrigation tube segment 48, into the primary
fluid passage 35 of the tip electrode 36, and out
10 through the porous material of the tip electrode. Because the
primary fluid passage 35 extends distally a greater length
than the blind hole 31, the fluid can pass outwardly on all
sides of the distal end of the primary fluid passage 35.

15 The fluid introduced through the catheter is preferably a
biologically compatible fluid, and may be in a gaseous or
liquid state. Suitable fluids include saline, water, carbon
dioxide, nitrogen, and helium. In addition to, or instead of,
being used to cool the tip electrode, the infused fluid also
forms a buffer layer to maintain biological materials, such as
20 blood, at a distance from the tip electrode, thereby
minimizing contact of the tip electrode with the biological
material. This buffer layer reduces coagulation of biological
materials and regulates the impedance or resistance to energy
transfer of the tissue near the tip electrode during ablation.

25 The rate of fluid flow through the catheter may be
controlled by any suitable fluid infusion pump or by pressure.
A suitable infusion pump is the FLOGARD™ available from
Baxter. The rate of fluid flow through the catheter
preferably ranges from about 0.5 ml/min to about 30 ml/min,
30 more preferably from about 5 ml/min to about 15 ml/min.
Preferably, the fluid is maintained at about room temperature.

35 As shown in FIG. 7, a temperature sensing means 41 is
provided for the tip electrode 36 and, if desired, the ring
electrodes 39. Any conventional temperature sensing means 41,
e.g., a thermocouple or thermistor, may be used. With

1 reference to FIG. 3B, a preferred temperature sensing means 41
for the tip electrode 36 comprises a thermocouple formed by a
wire pair. One wire of the wire pair is a copper wire 41a,
e.g., a number 40 copper wire. The other wire of the wire
5 pair is a constantan wire 43, which gives support and strength
to the wire pair. The wires 41a and 43 of the wire pair are
electrically isolated from each other except at their distal
ends where they contact each other and are twisted together,
covered with a short piece of plastic tubing 45, e.g.
10 polyimide, and covered with epoxy. The plastic tubing 45 is
then attached by polyurethane glue or the like in the first
blind hole 31 of the tip electrode 36. The wires 41a and 43
extend through the first lumen 30 in the tip section 14.
Within the catheter body 12, the wires 41a and 43 may extend
15 through the protective sheath 49 with the lead wires 44. The
wires 41a and 43 then extend out through the control handle 16
and to a connector (not shown) connectable to a temperature
monitor (not shown).

20 Alternatively, the temperature sensing means 41 may be a
thermistor. A suitable thermistor for use in the present
invention is Model No. AB6N2-GC14KA143E/37C sold by
Thermometrics (New Jersey). The temperature sensing means may
also be used as a feedback system to adjust the flow rate of
25 the fluid through the catheter to maintain a desired
temperature at the tip electrode.

30 A puller wire 50 extends through the catheter body 12, is
anchored at its proximal end to the control handle 16, and is
anchored at its distal end to the tip section 14. The puller
wire 50 is made of any suitable metal, such as stainless steel
or Nitinol, and is preferably coated with Teflon® or the like.
The coating imparts lubricity to the puller wire 50. The
puller wire 50 preferably has a diameter ranging from about
0.006 inches to about 0.010 inches.

35 A compression coil 52 is situated within the catheter
body 12 in surrounding relation to the puller wire 50. The

1 compression coil 52 extends from the proximal end of the catheter body 12 to the proximal end of the tip section 14. The compression coil 52 is made of any suitable metal, preferably stainless steel. The compression coil 52 is
5 tightly wound on itself to provide flexibility, i.e., bending, but to resist compression. The inner diameter of the compression coil 52 is preferably slightly larger than the diameter of the puller wire 50. The Teflon® coating on the puller wire 50 allows it to slide freely within the compression coil 52. If desired, particularly if the lead
10 wires 44 are not enclosed by a protective sheath 49, the outer surface of the compression coil 52 can be covered by a flexible, non-conductive sheath, e.g., made of polyimide tubing, to prevent contact between the compression coil 52 and any other wires within the catheter body 12.
15

The compression coil 52 is anchored at its proximal end to the proximal end of the stiffening tube 20 in the catheter body 12 by glue joint 51 and at its distal end to the tip section 14 by glue joint 53. Both glue joints 52 and 53
20 preferably comprise polyurethane glue or the like. The glue may be applied by means of a syringe or the like through a hole made between the outer surface of the catheter body 12 and the central lumen 18. Such a hole may be formed, for example, by a needle or the like that punctures the outer wall
25 22 of the catheter body 12 and stiffening tube 20 which is heated sufficiently to form a permanent hole. The glue is then introduced through the hole to the outer surface of the compression coil 52 and wicks around the outer circumference to form a glue joint about the entire circumference of the compression coil 52.
30

The puller wire 50 extends into the second lumen 32 of the tip section 14. The puller wire 50 is anchored at its distal end to the tip section 14. Preferably, an anchor is fixedly attached to the distal end of the puller wire 50, as
35 depicted in FIGS. 3A and 9. The anchor is preferably formed

1 by a metal tube 55, e.g. a short segment of hypodermic stock,
which is fixedly attached, e.g. by crimping, to the distal end
of the puller wire 50. The tube 55 has a section that extends
a short distance beyond the distal end of the puller wire 50.
5 A cross-piece 53 made of a small section of stainless steel
ribbon or the like is soldered or welded in a transverse
arrangement to the distal end of the tube section 55, which is
flattened during the operation. This creates a T-bar anchor.
A notch is created in the side of the tip section 14,
10 resulting in an opening into the second lumen 32 into which
the puller wire 50 extends. The anchor lies partially within
the notch. Because the length of the ribbon forming the
cross-piece 53 is longer than the diameter of the opening into
the lumen 32, the anchor cannot be pulled completely into the
15 lumen 32. The notch is then sealed with polyurethane glue or
the like to give a smooth outer surface. Within the second
lumen 32 of the tip section 14, the puller wire 50 extends
through a plastic, preferably Teflon® sheath 56, which
prevents the puller wire 50 from cutting into the wall of the
20 tubing 19 when the tip section is deflected.

In an alternative arrangement, as shown in FIG. 5, a
single lumen side arm 58 is fluidly connected to the central
lumen 18 near the proximal end of the catheter body 12. The
first irrigation tube segment 46 extends through the catheter
body 12 and out the side arm 58, where it terminates in a luer
25 hub (not shown) or the like. The side arm 58 is preferably
made of the same material as the outer wall 22, but preferably
has a greater thickness, e.g. 0.0275 inches. Where the side
arm 58 meets the catheter body 12, a molded joint can be
provided to provide additional strength and support. The
30 molded joint can be made of any suitable biocompatible
material, and is preferably made of polyurethane.

Longitudinal movement of the puller wire 50 relative to
the catheter body 12, which results in deflection of the tip
35 section 14, is accomplished by suitable manipulation of the

1 control handle 16. A suitable control handle for use with the
present invention is described in U.S. Patent No. 6,120,476,
the disclosure of which is incorporated herein by reference.

5 In another preferred embodiment according to the
invention, an electromagnetic sensor 64 is provided in the
distal end of the tip section 14. As shown in FIG. 9, in this
embodiment the tip electrode 36 is connected to the tubing 19
of the tip section 14 by means of a plastic housing 66,
preferably made of polyetheretherketone (PEEK). The tip
10 electrode 36 has a proximal section 68 and a distal section
70. The proximal section 68 of the tip electrode 36 has an
outer diameter less than the outer diameter of the distal
section 70. Thus, in the depicted embodiment, the proximal
section 68 forms a recessed stem that fits inside the distal
15 end of the plastic housing 66, and the distal section 70 is
exposed. The proximal section 68 is bonded to the housing 66
by polyurethane glue or the like. The proximal end of the
plastic housing 66 is bonded with polyurethane glue or the
like to the distal end of the tubing 19 of the tip section 14.
20 Preferably, the plastic housing 66 is about 1 cm long.

25 In this embodiment, the tip electrode 36 preferably has a
total length ranging from about 6 mm to about 9 mm, more
preferably about 7 mm. For a 7 mm long tip electrode, the
distal section 70 and proximal section 68 each preferably have
a length of about 3.5 mm. The proximal section 68 is formed
30 of a solid metal material. The distal section 70 is formed of
a porous material, as described above. However, the tip
electrode 36 could be modified so that a portion of the
proximal section 68, which is formed of a solid material, is
exposed along with the distal section 70, which is formed of a
porous material. Alternatively, a portion of the distal
35 section 70 could form a part of the stem that extends into the
housing 66. However, in the preferred embodiment, the entire
porous distal section 70 is exposed and the entire solid
proximal section 68 is contained within the housing 66.

1 A generally hollow cavity **72** is formed in the proximal
end of the proximal section **68** of the tip electrode **36**. The
electromagnetic sensor **64** is mounted partially in the plastic
housing **66**, partially in the cavity **72**, and partially in the
5 flexible tubing **19**, in a manner similar to that described in
U.S. Patent No. 6,120,476, the disclosure of which is
incorporated herein by reference.

10 The tip electrode **36** has a fluid passage **35** and a blind
hole **31** that extend longitudinally from the cavity **72**. The
second irrigation tube segment **48**, puller wire **50**,
thermocouple wires **41** and **43**, and tip electrode lead wire **44**
are mounted in the tip electrode. The electromagnetic sensor
64 is connected to an electromagnetic sensor cable **65**, which
extends through the third lumen **34** of the tip section **14**,
15 through the central lumen **18** of the catheter body **12**, and into
the control handle **16**. The electromagnetic sensor cable **65**
then extends out the proximal end of the control handle **16**
within an umbilical cord (not shown) to a sensor control
module (not shown) that houses a circuit board (not shown).
20 Alternatively, the circuit board can be housed within the
control handle **16**, for example, as described in U.S. Patent
No. 5,964,757, the disclosure of which is incorporated herein
by reference. The electromagnetic sensor cable **65** comprises
multiple wires encased within a plastic covered sheath. In
25 the sensor control module, the wires of the electromagnetic
sensor cable are connected to the circuit board. The circuit
board amplifies the signal received from the electromagnetic
sensor and transmits it to a computer in a form understandable
by the computer by means of the sensor connector at the
proximal end of the sensor control module. Also, because the
30 catheter is designed for single use only, the circuit board
preferably contains an EPROM chip which shuts down the circuit
board approximately 24 hours after the catheter has been used.
This prevents the catheter, or at least the electromagnetic
35 sensor, from being used twice. Suitable electromagnetic

1 sensors for use with the present invention are described, for
example, in U.S. Patent Nos. 5,558,091, 5,443,489, 5,546,951,
5,568,809 and 5,391,199 and International Publication No. WO
95/02995, the disclosures of which are incorporated herein by
5 reference. A preferred electromagnetic sensor **64** has a length
of from about 6 mm to about 7 mm and a diameter of about 1.3
mm.

10 Preferably, in this embodiment, the catheter body does
not comprise a stiffening tube **20**, because additional space is
needed within the central lumen **10** to include the
electromagnetic sensor cable. The catheter body in this
embodiment has an outer diameter preferably no greater than
about 8 french, more preferably from about 7 french to about
7.5 french, and if desired, no greater than about 5 french.

15 In the above-described embodiments, the tip electrode is
described as having a fluid passage and a blind hole. As
would be recognized by one skilled in the art, the tip
electrode could have only a fluid passage into which all of
the tubes, wires, etc. extend. However, such a design is less
20 desirable because the thermocouple would be in direct contact
with the fluid, which can result in an inaccurate temperature
reading.

25 If desired, the catheter can be multidirectional, i.e.,
having two or more puller wires to enhance the ability to
manipulate the tip section in more than one direction or to
form two or more different curves. Such a design is described
in U.S. Patent No. 6,123,699, the disclosure of which is
incorporated herein by reference.

30 The preceding description has been presented with
reference to presently preferred embodiments of the invention.
Workers skilled in the art and technology to which this
invention pertains will appreciate that alterations and
changes in the described structure may be practiced without
meaningfully departing from the principle, spirit and scope of
35 this invention. Accordingly, the foregoing description should

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1 not be read as pertaining only to the precise structures
described and illustrated in the accompanying drawings, but
rather should be read consistent with and as support for the
following claims, which are to have their fullest and fairest
5 scope.

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